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Travelling Wave Tube Amplifier, DSCS II, Satellite 9441

THIS REPORT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Presents the results of an investigation of the cause of failure of a 20 watt amplifier considering orbital data and laboratory simulation. Ascribes the failure to the power supply (not the tube) and suggests a probable cause.

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SATELLITE 9441
20 WATT TWTA ANOMALY REPORT

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CONTENTS

1. INTRODUCTION

At 0240 hours (Zulu) on January 25, 1980, narrow coverage high level amplifier "B" ceased operating. This is Model 1202 Amplifier Serial Number 24-27, containing TWT SN 527. The unit, per standard contingency procedure, was commanded "on", did not respond, and was commanded "off" and the "A" unit turned on.

2. TELEMETRY INDICATIONS

The last previous pass showed telemetry readings essentially identical with the amplifier acceptance data. After communication was lost, the unit telemetries were as shown in Table I. The indication is of a unit with no high voltages on, slightly low filament voltage, and a corresponding low input power.

3. BUILD AND TEST HISTORY

There is no comparable failure recorded against this or any other Model 1202 Amplifier, at Hughes *(manufacturer of the amplifier)*, TRW, or in orbit.

Tube 527 had a single hi-pot trip at the cathode in manufacturing test. This is considered acceptable if two retests show no repeat, which was the case.

There is one failure report recorded for this unit, V29938. This documents a failure to turn on ascribed to an open 1N4148 diode. The semiconductor module was replaced. Through the F12 build, compression bonded 1N4148's were used. Two modules were replaced in 1200 (low level) amplifiers for similar problems and separate test of the parts showed a tendency to open or partially open under thermal cycling. F13 and subsequent build uses metallurgically bonded parts which are not subject to this failure mode.

4. DIAGNOSIS

The nature of the failure can be explored by first eliminating causes which could not produce the observed symptoms. Appendix I shows relevant test results obtained by Hughes in support of this report.

TABLE I

NORMAL VS FAILED DATA, TWTA S/N 24-27

FUNCTION	RECORDED TLM VOLTAGES (POST-FAILURE)	TLM TRANSLATED VALUES (POST-FAILURE)	NORMAL VALUE
CATHODE VOLTAGE	.22 V	3446 V*	3805 V
CATHODE CURRENT	.04 V	.55 mA*	53 mA
FILAMENT VOLTAGE	3.74 V	4.98 V	5.6 V
HELIX CURRENT	.06 V	.07 mA*	.7 mA
INPUT CURRENT	.3 V	.36 A	3.2 A
PLATFORM TEMPERATURE	N.A.	68.5 °F	~92° F

*Indication is characteristic of zero actual value.

a. Short circuits at the tube (or high voltage wiring) produce excess input power or trip the input overcurrent protect. By test, Table I-I and I-II, the amplifier trips with 160 kΩ to ground at the collector, 400 kΩ to ground at the cathode. Up to the trip point the amplifier will operate, drawing excess input current. Since the amplifier has not tripped (filament voltage is still "on") and is not drawing excess current, the problem is not a high voltage short.

b. The low filament voltage shows the unit is not in a normal warm-up mode.

c. The combination of low filament voltage, lack of high voltage, and low input current shows the unit does not have a failure in the filament supply.

d. The existence of any filament voltage and the low input power shows the unit does not have an excess load on the 17 or 19 volt bus.

A reasonable possibility remaining may be seen by noting that the only way to get a low filament voltage with the above limitations is to assume the 19 volt bus has dropped to below 17 volts, e.g., to about 15 volts. Under this condition the high voltage section will draw approximately 0.5 amp or less current, and all the symptoms match. While analysis beyond this point must be speculative, Hughes has developed a reasonable hypothesis which explains the failure in terms of previous history as follows. Since a 1N4148 failure was a likely possibility, tests were performed to show the effect at each circuit location. Results are shown in Table I-III.

5. POSSIBLE FAILURE CAUSES

Table II contains a brief summary of possible failures with comments as to the possibility and/or probability based on the symptoms gathered from Table I.

Referring to schematic B200350-210 Sheet 2, a portion of which is shown in Figure 1, it will be noted that the 19 volt bus voltage regulator is controlled by the impedance of A4-CR3 (zone D12). CR3 is a IN4148. If it should fail to a high impedance (approximately 1.5kΩ), the 19 volt bus is controlled to a low voltage. The switching regulator transistor, Q8 (2N3599) (zone C14), then runs in a linear mode at high power and thus fails. Hughes part specialists advise that the likely failure is to a fixed relatively high impedance (approximately 9Ω). The 19 volt bus is then permanently at a low (random) voltage and the observed symptoms are observed.

The symptoms were duplicated by Hughes by setting up the above sequence of events in the breadboard power supply. Table I-IV A, B and C show the resulting amplifier behavior.

6. CONCLUSION

The failure appears to be an isolated occurrence. The most likely cause is a failure in a part not used in later builds. The current production 40 watt amplifier has little in common with the 20 watt design. No further action is recommended as far as the DSCS II high level amplifiers are concerned.

It was noted during this analysis that a small change in Orbital Operating Procedure would provide extra diagnostic information in the event of anomalous amplifier behavior.

To date, the practice has been to command an apparently failed amplifier "on" (without sending "off"), to check that the unit has not been inadvertnetly shut down by the satellite. If this produces no result, the redundant unit is commanded "on".

TABLE II

POSSIBLE FAILURES

FAILURE MODE	COMMENTS (PROBABLE SYMPTOM)
COLLECTOR ARC("SHORT CIRCUIT")	UNIT WOULD TRIP OFF
CATHODE ARC/SHORT	UNIT WOULD TRIP OFF
HIGH VOLTAGE MODULE "SHORT"	UNIT WOULD TRIP OFF
HEATER MODULE "SHORT"	UNIT WOULD TRIP OFF
HIGH VOLTAGE "OPEN"	INTERNAL BUS CLIMBS: E_F GOES HIGH
HEATER MODULE "OPEN"	NO HEATER VOLTAGE
FAILED MAIN SWITCH	POSSIBLE; - BUT NOT PROBABLE. TRANSISTOR HEAVILY DERATED WITH EXCELLENT HISTORY. (NO KNOWN PRIMARY FAILURES)
FAILED DIODE ON LOGIC BOARD	POSSIBLE, (HIGH QUANTITY OF 1N4148'S WITH KNOWN FAILURES) BUT NOT PROBABLE BASED ON KNOWN SYMPTOMS. (SEE TEST DATA IN APPENDIX I; TABLE I-IIIA)
FAILED DIODE IN CONVERTER	POSSIBLE, BUT NOT PROBABLE BASED ON KNOWN SYMPTOMS. (SEE TEST DATA IN APPENDIX I)
FAILED DIODE IN REGULATOR	POSSIBLE, WITH HIGH PROBABILITY, BASED ON KNOWN SYMPTOMS. (TEST DATA CONFIRMS)

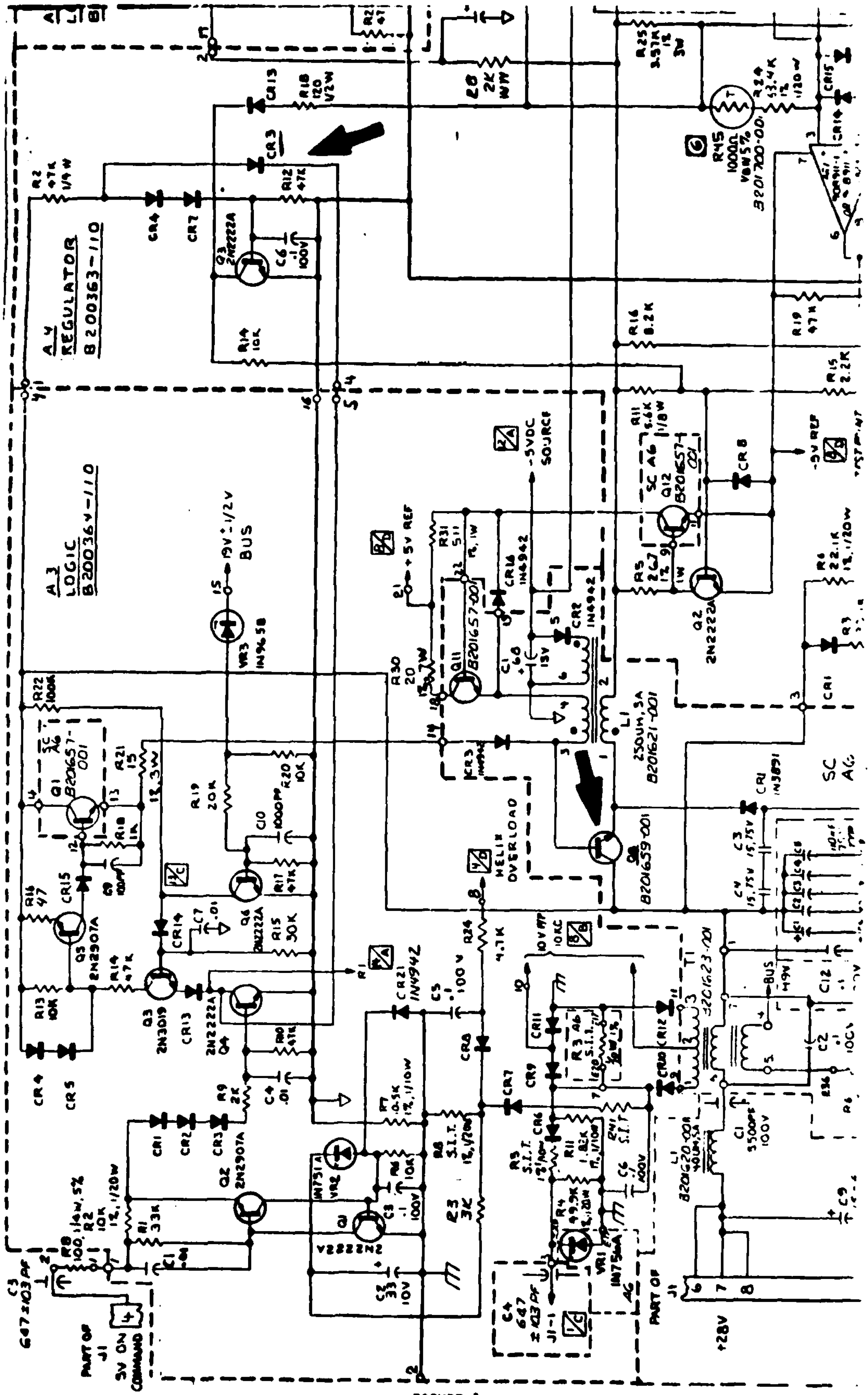
A3 LOGIC
B200364-110
A4 REGULATOR
B200363-110
19V ± 1/2V BUS
HELIX OVERLOAD
-5VDC SOURCE
+5V REF
-5V REF
PART OF J1
5V ON COMMAND
+28V

FIGURE 1

It is proposed that the following sequence would provide more information: While recording telemetries;

A. Command the "failed" unit "ON".

B. If unit fails to come "ON", send "OFF" command.

C. Transmit "ON" command timed to filament voltage readout (20W TWTA's only), and after waiting between 30 to 60 seconds, transmit the "OFF" command.

D. Switch to the redundant unit.

APPENDIX I

Ref: TRW Report No. 36060-AR-021-01

As an assistance to TRW's investigation of an anomaly involving 1202HA TWTA S/N 24-27 on DSCS IIR Spacecraft 9441, a series of tests and analyses were performed at Hughes, EDD.

The tests performed were centered around:

a) Simulate a shorted collector-to-ground
b) Simulate a shorted cathode-to-ground
c) Simulate an "open" 1N4148 diode
d) Special situation simulations

The tests were performed on the 1202HA breadboard, wherein, the Helix overcurrent trip had been disabled and the input current trip left enabled (as per the units on 9441 and 9442), and using 265HC TWT S/N 511 as the load.

Tests (a) and (b) were performed by placing a decade resistance box in parallel with the particular element and reducing the resistance. The results of these tests are shown in Tables I - I and I - II, respectively. As can be seen from the data, the input current increased until the input overcurrent protect circuit tripped.

Test (c) was performed by allowing the unit to "time-out" as normal, then opening the particular diode. The results are shown on Tables I - IIIA and I - IIIB. Of particular note is the data on the first line of Table I - IIIB, A4-CR3. This data was near enough to the telemetered data from Spacecraft 9441 that it was investigated further to see if a particular failure mode could even more closely approximate the Spacecraft data. The results are shown in Table I - IVA.

Again using a decade resistance box, the series resistance of A4-CR3 was increased until a malfunction was observed. This occurred at 1.57 Kohm, but again the data did not exactly simulate the orbital data. The main switching transistor, SC-Q8 was observed to begin overheating and it was hypothesized that this could eventually damage the transistor, causing a "high" C-E resistance. (In a subsequent test, the case temperature was actually caused to climb in excess of 230°C -466°F - and while the breadboard unit survived this temperature for several minutes, it is only a sample of one and is not configured in the same manner as a flight unit.)

A value of 9 ohm was added in series with SC-Q8, with the results shown in Table I - IVB. Previous test data observed by HEDD components reliability personnel have shown that both the 1.57 Kohm and the 9 ohm values are quite typical failure modes for these components. (SC-Q8 is a 2N3599 with a C-E resistance of 0.1 ohm maximum.)

Several other tests were performed on various components but none of the results showed the interrelationship and resultant data nearly as well as the test described above. (These test data are available in the anomaly log book for review.)

Further, since the information received from TRW indicates that this anomalous state continued for "hours" versus "minutes", it is reasonable to assume that SC-Q8 is now irreversibly damaged, even though A4-CR3 may "heal" itself, and the TWTA cannot be successfully turned back on. This is shown in Table I - IVC, wherein only the 9 ohm is left in series with SC-Q8 and the unit was observed to continuously time-out and recycle to zero.

ABBREVIATIONS/NOMENCLATURE GLOSSARY

Designator	Description
A1	Converter Board (B200365-XXX)
A3	Logic Board (B200364-XXX)
A4	Regulator Board (B200363-XXX)
SC	Semiconductor Module (B200362-XXX)
EK	Cathode Voltage
E_b	Collector Voltage
E_{htr}	Heater (Filament) Voltage for TWT
E.S.R.	Switching Regulator Voltage (Main Internal Bus)
L. BUS	Linear Bus Voltage (for Heater Supply)
I_w	Helix Current
A4-CR3	Diode NR. 3 (A 1N4148) on the A4 Board
SC-Q8	Transistor NR8 (A 2N3599) on the SC Chassis

TABLE I - I

1202HA COLLECTOR-TO-GROUND "SHORT"

#R(ohm)	=	1 Meg.	950K	900K	850K	800K	750K	700K	650K	600K	550K	500K	450K
Ein	=	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Iin	=	4.2A	4.2A	4.2A	4.2A	4.20	4.23	4.25	4.30	4.33	4.40	4.46	4.51
Ek	=	-3757	-3757	-3757	-3757	-3757	-3757	-3757	-3757	-3757	-3757	-3757	-3757
E.S.R.	=	20.14	20.14	20.14	20.15	20.17	20.18	20.19	20.21	20.24	20.27	20.31	20.35

#R(ohm)	=	400K	350K	300K	250K	200K	180K	170K
Ein	=	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Iin	=	4.60	4.7	4.82	5.02	5.3	5.5A	5.6
Ek	=	-3758	-3758	-3759	-3759	-3760	-3761	-3761
E.S.R.	=	20.40	20.47	20.56	20.69	20.88	20.99	21.05

TRIPS AT 160 Kohm

TABLE I - II

1202HA CATHODE-TO-GROUND "SHORT"

R(ohm) =	1 Meg.	950K	900K	850K	800K	750K	700K	650K	600K	550K	500K	450K
Ein =	27.8	27.8	27.8	27.7	27.7	27.7	27.7	27.6	27.6	27.5	27.5	27.4
Iin =	4.6	4.65	4.7	4.78	4.8	4.9	5.0	5.05	5.15	5.25	5.4	5.65
Ek =	-3758	-3758	-3758	-3758	-3758	-3758	-3758	-3759	-3759	-3759	-3760	-3760
E.S.R. =	19.72	19.74	19.76	19.78	19.80	19.83	19.86	19.90	19.94	19.99	20.05	20.15

TRIPS AT 400 Kohm

TABLE I - IIIA

1202HA OPEN 1N4148

Open								---------- TLM Voltage ---------				
A3	Ek	Eb	Iin	Ein	EHtr	E.S.R.	L. Bus	Iin	EHtr	Ek	Ik	Iw
CR1	0	0	0	29.4	0	0	0	0	0	0	0	0
CR2	0	0	0	29.4	0	0	0	0	0	0	0	0
CR3	0	0	0	29.4	0	0	0	0	0	0	0	0
CR4	-3754	-2358	3.4A	28.12	5.56	19.05	18.28	2.64	.381	1.49	2.57	.29
CR5	-3753	-2359	3.45A	28.13	5.56	19.06	18.28	2.65	3.81	1.49	2.58	.33
CR7	-3753	-2360	3.4A	28.16	5.56	19.03	18.28	2.71	3.81	1.48	2.57	.28
CR8	-3753	-2360	3.4A	28.12	5.56	19.03	18.28	2.63	3.81	1.47	2.57	.28
CR13	-3753	-2360	3.4A	28.15	5.56	19.03	18.28	2.63	3.81	1.47	2.57	.28
CR14	-3753	-2360	3.4A	28.17	5.56	19.04	18.28	2.64	3.81	1.47	2.57	.33
CR15	-3753	-2361	3.4A	28.13	5.56	19.02	18.28	2.63	3.81	1.46	2.57	.28
CR6	-3753	-2361	3.4A	28.13	5.56	19.02	18.28	0	3.81	1.46	2.57	.28
CR9	-3753	-2360	3.4A	28.15	5.56	19.02	18.28	2.33	3.81	1.46	2.57	.27
CR10	-3753	-2362	3.4A	28.13	5.56	19.00	18.28	1.50	3.81	1.46	2.57	.27
CR11	-3753	-2360	3.4A	28.13	5.56	19.01	18.28	1.49	3.81	1.41	2.57	.27
CR17	-3753	-2361	3.4A	28.08	5.56	19.00	18.28	2.62	3.81	1.45	2.57	.26
CR19	-3753	-2361	3.45A	28.03	5.55	19.04	18.28	2.66	3.82	1.48	2.58	.31
CR20	-3754	-2362	3.4A	28.03	5.55	19.00	18.28	2.64	3.82	1.45	2.57	.26

TABLE I - IIIB

1202HA OPEN 1N4148

Open								TLM Voltages				
A4	Ek ≈<	Eb ≈<	Iin	Ein	EHtr	E.S.R.	L. Bus	Iin	EHtr	Ek	Ik	Iw
CR3	-2270	-1397	.500	28.75	0	12.35	2.0	.37	.16	0	0	.28
CR4	-3754	-2359	3.4A	28.08	5.56	19.03	18.28	2.63	3.81	1.47	2.57	.28
CR7	-3754	-2363	3.4A	28.08	5.56	19.01	18.28	2.63	3.81	1.45	2.56	.26
CR13	-3754	-2362	3.4A	28.12	5.56	19.02	18.28	2.64	3.81	1.47	2.58	.31
CR2	-2748	-1699	3.4A	28.07	4.07	14.19	13.85	2.36	2.78	0	1.42	2.43
CR6	-2792	-1723	3.6A	28.04	4.16	14.49	14.18	2.45	2.85	0	1.51	2.46
CR9			UNIT TRIP OFF (INPUT OVERCURRENT)									
CR12	-2349	-1463	2.7A	28.47	3.50	12.56	12.29	1.46	2.43	0	.56	3.43
CR14	-3741	-2352	3.4A	28.09	3.56	18.94	18.28	2.61	3.81	1.41	2.55	.27
CR15	-3766	-2370	3.4A	28.08	5.56	19.06	18.28	2.65	3.81	1.49	2.58	.25
CR16	-3754	-2361	3.4A	28.08	5.56	19.02	18.28	2.63	3.81	1.46	2.57	.26
CR17	-3754	-2361	3.4A	28.08	5.56	19.02	18.28	2.63	3.81	1.45	2.57	.26
CR18	-3754	-2361	3.4A	28.08	5.56	18.99	18.28	2.62	3.81	1.45	2.56	.26
CR19	-3754	-2361	3.4A	28.08	5.56	19.01	18.28	2.63	3.81	1.45	2.57	.26
CR8	-3754	-2358	3.4A	28.09	5.56	19.06	18.29	2.64	3.82	1.49	2.57	.29
CR1	-2380	-1462	3.2A	28.21	3.53	12.68	12.46	1.58	2.49	0	.67	3.49
A1												
CR5	-1892	-1495	1.4A	28.8	4.63	22.95	18.40	.45	3.38	0	.60	2.21
CR10	-3754	-2364	3.45A	28.04	5.57	19.00	18.28	2.66	3.82	1.45	2.57	.26
CR11	-3754	-2363	3.4A	28.04	5.59	18.99	18.28	2.65	3.84	1.45	2.57	.26

TABLE I - IVA

1202HA A4-CR3 WITH 1.57 Kohm IN SERIES

					TLM Voltage				
Ek	Eb	Iin	EHtr	E.S.R.	Iin	EHtr	Ek	Ik	Iw
-2325	-1425	1.7A	3.28V	11.90	0.99	2.27	0	0.24	2.88

TABLE I- IVB

A4-CR3 WITH 1.57 Kohm IN SERIES
SC-Q8 WITH 9 OHM IN SERIES (C-E)

					TLM Voltage				
Ek	Eb	Iin	EHtr	E.S.R.	Iin	EHtr	Ek	Ik	Iw
0	0	0.5A	4.49V	15.43	0.20	3.10	0	0	0

TABLE I - IVC

SC-Q8 WITH 9 OHM IN SERIES (C-E)

					TLM Voltage				
Ek	Eb	Iin	EHtr	E.S.R.	Iin	EHtr	Ek	Ik	Iw
0	0	0.5	4.48	15.40	0.11	3.09	0	0	0

NOTE: UNIT CONTINUES TO CYCLE THROUGH TIME-OUT AND "RESTART"